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PROTOPLASMIC DYNAMICS.

BY PROF. W. S. BARNARD, PH.D.

THE present general tendency of natural science is towards unification. Formerly it was truly " natural history," analytically descriptive and distinctive, while morphological classifications were formed on external resemblances known as analogies, or on internal structural analogies entitled homologies. But this stage of culture has passed its maturity, while the investigation of processes has introduced the natural, synthetic, explanatory stage, with its abundant results now appearing.

The derivation of the physical forces from each other by transmutation, and from chemical and mechanical actions, which they are capable of originating again, the development of organisms from protoplasm, a substance, which, with its functions, all have in common, and the doctrine of the evolution of species, present only some of the most important advances made toward a unitarian system combining all objects and operations together as they are derived from each other. While some chemists expect that organic chemical combinations may yet be obtained by uniting inorganic molecules in the laboratory as in the bodies of plants, and there are those who think with Haeckel that the very lowest living forms may arise by spontaneous generation from the higher carbon compounds, the physiologists have decided that there are chemical changes and physical forces associated with, and seeming to have a causal connection with, the production of organic powers and functions. But there can be no positive certainty of this transition unless we can show *how* and *why* it necessarily results. To effect this and to attempt to trace out the systematic combination of some of the fundamental operations, whether physiological, mechanical, physical or chemical, as they exist in one continuous process pertaining to protoplasmic things, is my present undertaking.

I.—Protoplasm masses and molecules, or their parts, may be set in motion by the impact or attraction of active masses or molecules or atoms, without or within.

The agitations thus imparting themselves are various and, because communicative, may be regarded as excitants or incitive actions, already called stimuli or irritants. These include *mass-motions*, such as pressure, blows and friction; *molecular motions*, chiefly vibratory or oscillatory, as sound, electricity, light and heat; also *atomic motions;* and with these are the *attractions* belonging to these divisions of matter respectively, as gravitation (weight), cohesion and adhesion (osmotic, diffusive, capillary, &c.), and finally chemism. Important sources of some of these are the chemical reactions of oxygen, water, and the ingested nutriment, constituents with each other and with the protoplasm elements; others proceed from contact with the active materials of the environment; while the sun also continually contributes.

II.—All the above disturbing forces tend to cause the displacement, mutilation, fission or decomposition of molecules or their parts, which is especially easily accomplishable against weak combinations of ponderous, complex molecules, such as distinguish organic bodies.

III.—When molecules or their parts are thus separated, their combining powers are set free, and this liberation of attractional forces will be sustained by the continued operation of the original displacement forces, or may become, to some extent, self-propagated after their cessation by the disturbance (heat, &c.) resulting from recombination; for the impact of every union manifests itself in new disturbing force, which, in turn, may disband other attractions, from which further combinations follow.

An illustration of this self-sustained process is common in every form of combustion. The little heat-agitation applied to a very small part of the mass to be consumed, frees attractions there, which satisfy themselves by uniting with the ever-present oxygen, thereby generating more heat, sufficient to renew itself by inducing further chemical reaction so long as fed with the material for consumption.

IV—These free combining powers, acting together, constitute plasma attraction or affinity, and are the force and source of organic power. Their mode of utilization we shall see further on.

Though strange indeed that attraction as the great fountain of power in organisms has been overlooked, it has probably remained so from lack of seeing the application of this most abundant of all forces to the driving of the vital machine, even as we were late in learning the use of the expanding power of steam. Without looking among the attractions for the propelling power, the impression has prevailed that if anything is necessary, more than the assumption of an independent vital force, it must be looked for in forces like heat and electricity, which are freed by chemical combination, and evidently are of great importance, especially in the higher organisms as communicative and excitive of agitations inducing the liberation of attractions which collectively constitute the immediate organizing and working power. Concerning this matter Herbert Spencer (Princ. Biol., Vol. 1, pp. 55) says, "*We have as yet no clue to the mode in which molecular movement is transformed into the movement of masses.*"

Also in this connection three papers may be cited as fairly showing the chief facts and theories bearing on this question and respectively pertaining to the three kinds of active tissues of the higher organisms:

1. Engelmann. Die Flimmerbewegung. Jenaische Zeitschrift, Vol. IV, 1868.
2. Charles. The mode of Propagation of Nervous Impulses. Journal of Anatomy for October, 1879.
3. Armsby. The source of Muscular Power. Popular Science Monthly for October, 1879.

The first of these is an exceedingly important volume of investigations, showing the effects of chemical re-agents, and the physical and mechanical forces in accelerating or retarding, introducing or stopping the action of dead and living cilia, also affirming the constancy and fundamental importance of the *imbibitional swelling*, and the conclusions of others, that *like reactions are obtained from all the contractile tissues.*

The second defines the two propagation-processes attributed to nerve impulses; the *vibratory* hypothesis and the *chemical* hypothesis, giving the facts on which the latter is founded, with the conclusion that it necessarily partly includes the former.

The final decision will probably be that both these processes exist throughout the gray protoplasm of the nervous system, but that the chemical predominates in the ganglial cells, the vibratory in the axial plasma.

The third is a presentation of the chief facts and conclusions pertaining to its subject, and with such decided bearings on the topic before us that we must notice it more particularly. By way of introduction the following statements represent a doctrine which is now largely taught and accepted.

> "The question of the source of muscular power is essentially a question concerning *transformation of energy.* The most characteristic distinction between plants and animals is, that the former *appropriate force from outside themselves, from sunlight, and store it up as potential energy in the various complex compounds which they form in;* while animals draw their supplies of force entirely from those compounds in which it has been stored up by plants, and from which it is set free again when they are decomposed in the organism."
>
> "In a word, the plant converts the actual energy of the sunlight into the potential energy of organic compounds, the animal converts the potential energy of the organic compounds into actual energy, which manifests itself as heat, motion, electricity, etc.; in the plant the spring is coiled up, in the animal it uncoils, exerting an amount of energy equivalent to that which coiled it. One of the forms which this energy takes on is that of *muscular motion*, which we thus trace back to the *potential energy of food*, and through this to that great source of all energy to our earth, *the sun.*"
>
> "We are not, however, satisfied with knowing in this general way that it is *the food* we eat which *serves as a vehicle to convey to us our needful supply of sun-force.*"

We agree that there is "energy of food," that "plants store up * * * * energy in the various complex compounds which they form in," but when it is called "sun-force" appropriated "from sun-light" and stored up, we dissent, for it is attractional force inherent in terrestrial matter independent of the sun, and from which probably none has been received since our globe was a part of her fiery mass. Similarly Professor Carpenter (Correlation and Conservation of Forces, pp. 404–5) speaks, "Thus in either case we come, directly or indirectly, to solar radiation as the main spring of our mechanical power; the *vis viva* of our whole microcosm." And thus too much power is now-a-days often attributed to the present influence of the sun and the undulatory forces, and too little to the attractional forces of matter. The author speaks of the force several times as "potential" and "latent" energy, but these words in such connection are worth no more than blanks. This valuable conclusion agrees with that of Professor Flint (and others),—"All the facts seem to indicate that muscular force originates in *a splitting up of some substance in the muscle accompanied by the liberation of force*" (p. 822). The next conclusion should be that *combining power* is the only *immediate* force that can be freed by fission among muscle molecules. This will appear if we thoroughly understand the nature and relations of the powers in question, for it is necessary to distinguish all forces sharply into two groups: 1, the *attractional* (gravity, adhesion, cohesion, chemism), and 2, the *impactive* or momentum forces of masses, molecules and atoms (in mass-motions, sound, electricity, heat and light). Those of one group are *not convertible* into, but *oppose* those of the other, and while the latter set may, by opposition, often disengage the former, the latter are but the *recoil* (which may propagate itself) from the actions produced by the former group.

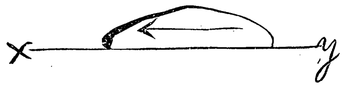
V. The plasma-affinity, which is the joint action of its freed attractions, is its imbibing force, exerting a hydraulic suction power, manifested in a circulation into the part affected and the resultant swelling of the same, from which all the mass motions of organisms proceed.

The initial movement is the circulation among the attracting molecules with its general direction toward the point where the greatest amount of chemismic power is being freed, and such as necessarily precedes chemical unions of dilute fluid constituents with those of fixed, elastic, porous bodies; for the matter imbibed consists of the water solution of oxygen, nutriment and disengaged plasma-molecules. Most common examples of expansive and circulatory movements resulting from combining power are not in their details parallel with those of the protoplasmic substance. The activities from heat and from affinities freed by heat in ordinary combustion, which naturally come to mind first, present an altogether different case. If the combining element, oxygen, was only in a solution permeating everywhere to act throughout the entire mass, the resultant activity would be, instead of a swelling of heated surrounding air, an expansion of the solid mass. And we must also remember that the protoplasm contains, besides oxygen, many other reagents as its stored food-constituents; that there are also more of the volatile elements in its composition, which is more complex while its consistency is that of elastic viscosity. Further, the oxidation in organic fluids cannot be so intense and generates but a comparatively small amount of heat, so little that it is eliminated by conduction without appearing in such vast quantities as to induce a boiling or convectional circulation, while the chemical reactions of the organized plasma-components are exceedingly slow and weak, yielding but little heat.

The intersusception and interpolation of new matter into the plasma is by *imbibition*, which also is the method of ingestion of nutriment by the plasma of cells and the lowest organisms. This imbibition process is a well-established concomitant to all plasma-action, but while its value as a nutritive power determining the peculiarities of nutrition and growth has been esteemed, its great importance in the production of *mass-motions* has not become understood.

VI.—*Imbibitional swelling*, in some respects, simulates that resulting from inorganic absorption and diffusion, but is markedly different, especially since the engaged combining powers act stronger than those freed, so that it does not result in a dissolution or solution of the imbibing substance, while the increase of distension intensifies its tension and elasticity. To understand the possibility of this swelling without rupture of the chemismic bonds in organic bodies, we may have to regard their constituents as grouped into filamentous branches or a spongy mesh, in symmetrical order, and remember that they are certainly very complex, for, according to recent chemical theories, some of the albumenoid molecules may contain a thousand atoms.

Let us now classify the principal *kinds of plasma-motion* while trying to explain how each is attained.

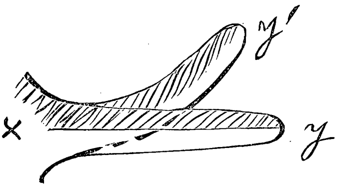


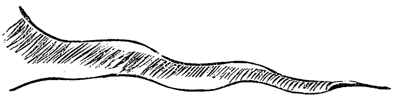
1. *Axial Procession.*—Let x—y represent a surface on which a a lump of plasma is shown in section, the heavy portion of its outline indicating that part of its surface which is acted on by light or some other decomposing force. Imbibition from within to this tract is induced and it swells thereby advancing slightly toward the light, while gravity pulls it down so that an advancing descending movement of the front margin

results while the upper and inner adjacent plasma supplies its place to swell and follow, and so on, the mass advances. This kind of motion is very common in some Amœbas.

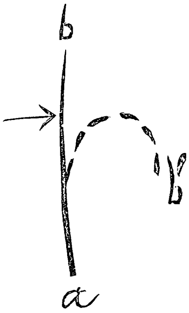
2. *Axial Exsertion.*—The imbibitional swelling may be still more local from either external or internal excitation and thereby produce pseudopodal protuberation, and in Amœbas we often observe the transition from the pseudopodal to the total procession. In both cases these animals show a marked circulation towards the swelling point in the protruding part.

3. *Lateral Deflection* may be produced in any elongated mass by lateral superficial imbibitional swelling, as in the light area of the pseudopod *x—y* causing its deflection to *x—y′*. By this method alternating from side to side, the vibrations of the pseudopods of free-swimming, rotating rhizopods and the flagellate and ciliate action of infusorians, rotifers and other organisms are effected, probably under control of electro-chemical impulses in their own substance. The sort illustrated above may be called the monomeric while the polymeric or undulatory form also appears as shown in the figure, the white swollen regions being several and alternately disposed. Again, should the imbibition follow a spiral line, spiral contortions and cycloidal figures result.



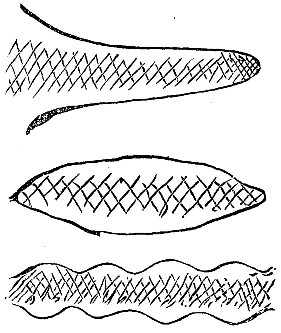


A good method of showing imbibitional deflection is to use a very thin strip of gelatin, such as is employed by lithographers for tracings. Let *a–b* represent the sheet as seen edgewise and standing erect, held at *a*. Now if it be breathed on gently at the point indicated by the arrow, it will quickly bend over to *b′*. This is by imbibition of the moisture of the breath on one side causing it to swell. The thinner the sheet is the quicker will the flexure appear, and by comparison we may judge that with filaments as fine as cilia it should result with the same rapidity that characterizes cilia motion. The thin mass erects itself as promptly of its own accord, but still more sudden if moisture be breathed



on the opposite side. And thus by breathing on one side and then on the other the vibration back and forth may be produced several times. Of course, in actual cilia the conditions are very different, for the material to be imbibed is ever present, while the imbibitional attraction is alternately freed first on one side and then on the other apparently by a chemico-electric, electro-motor process. And those who think it necessary to suppose a vital force here must be reminded that, according to Engelmann (op. cit. pp. 463–4), weeks after death, on stinking, decaying membranes, the cilia can be set in action by adding their normal conditions of oxygen, water and temperature.

4. *Zonate expansion with axial contraction*, in a monomeric form pertains especially to such retractile parts as pseudopods, some cilia, and unstriated muscle cells, from imbibition in a zone of the conical or cylindriform part. The engorgement of this zone causes an influx into it shortening the long axis and tending to yield a spheroid form. In this way muscle cells and pseudopods broaden and shorten themselves, the latter sometimes to such an extent as to attain the diameter of the main mass, into which they thus merge. In the diagrams the light parts represent the expanding zones. With the polymeric form of the striated muscle cells, undulatory outlines result from the swelling of many successive zones giving greater and quicker contraction than in the smooth spindle cells. In this connection it must be borne in mind that a muscle's action is only a resultant of the joint action of all its cells and that attraction is the *vis a tergo* of organic expansion and contraction.



5. *Contra-actional retraction* we can presume as the reverse of the exsertive, its center of imbibition being at the base of the pseudopod which becomes drawn to it.

6. *Sphærogenic ballancement* would occur from equal expansion in all directions and cause the mass to assume a spherical form.

VII.—The processes described above produce all the *mass-motions* of organisms, which are of many kinds and may be chiefly grouped as:

1. *Locomotive*, for transporting individuals from place to place.

2. *Supportive*, for maintaining the normal relative position of parts and opposing gravity.

3. *Prehensional*, including all kinds of manipulatory actions.

4. *Peristaltive*, the motor actions of hollow organs on their contents, embracing swallowing, gastrition, peristaltition, the contractions of sphincters, the heart, blood-vessels (circulative), &c.

VIII.—The molar and mass-impact and frictional wear and tear from the above operations yield mechanical heat and electricity with structural degeneration.

IX.—To maintain the conditions of all these activities the combining process must go on intermittingly or constantly. The fractional molecules must unite with each other, with imbibed food-constituents (nutritive assimilation) or with oxygen.

X.—From this we have chemical heat and electricity with the processes of protoplasmic extraction, secretion and excretion of fluids. Though heat and electricity must naturally appear more or less from all the chemical unions in plasma of whatever tissues, we may look upon the oxidizing process as the greatest source of chemical heat, while the ganglial and muscle cells are to be looked upon as the batteries in which chemical combination generates most of the neural electricity. To illustrate the relations existing here, we may suppose the light to cause molecular agitation in the retinal nerve-ending and to propagate itself inward. Entering the ganglial plasma, it frees attractions, whence recombination results, generating nerve electricity discharged along the motor nerve and naturally causing some chemical reaction in it, but producing its greatest effect in the terminal muscle cell, which is charged as a receiver, the continued agitation keeping its attractions freed, sustaining imbibitional zonate expansion with axial contraction, from which mass-motion results. In the so-called voluntary motion it would seem as though the ganglial agitation was excited from within and the same consequences follow. The recombination occurring in the muscle substance probably also generates recurrent electricity, which reacts upon the nerve centers.

Finally, organic combining power is not only motor power, but also "growth-force," the *vis a tergo* of plasma-nutrition, growth and development, producing (by coöperation with conditioning forces) all the diverse and wonderful form-phenomena, the kinds of which, like the varieties of mass-motion, are determined through localized imbibition. On this account, and because the motor acts have laid out the paths of growth, the parallelism between the series of morphological processes and of the motor processes is strikingly complete; but a presentation of these details, in the same order, must remain for the future.

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A SKETCH OF COMPARATIVE EMBRYOLOGY.

BY CHARLES SEDGWICK MINOT.

II.—THE FERTILIZATION OF THE OVUM.

IN the previous article we traced the relation of the genoblasts, or sexual products, to the cells from which they arise. We have now to consider the manner in which these products effect the creation of a new and complete animal. Now, the bodies of all animals are composed of cells and the productions of cells, hence to make an animal the first thing is to furnish cells. According to the theory propounded in the last article, an egg represents one part, a spermatozoön another part of a cell, hence a fusion of the two would again make a single perfect cell. This fusion actually occurs, and is called the impregnation or fertilization of the ovum.

Our knowledge of this phenomenon is extremely imperfect. It has, however, been the object of several important researches during the last few years, but we must wait for much more extended investigations before we can make any satisfactory generalizations. The following order of events is that which our present knowledge renders most probable—it must be remembered that we are dealing only with a probability. A *single* spermatozoön enters the egg and fuses with it. After the ejection of the polar globules, the nucleus of the egg is a small body which lies near the periphery, immediately underneath the globules. It then is called the *female pronucleus*, and travels—why or how is not known—towards the center of the egg, where it finally remains. A system of radiating lines runs out from it into the yolk, making, together with the pronucleus, the so-called female *aster*.